

Millimeter Wave Focal Plane Array Technology

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LONG-TERM GOALS

To provide a lightweight, low power and low cost passive millimeter wave (PMMW) imager capable of supporting Naval Special Warfare (NSW) and the Special Operations Command (SOCOM) Technology Development Objective for enhanced vision capabilities.

OBJECTIVES

To demonstrate operationally useful performance in a passive, staring millimeter wave focal plane array of antenna-coupled microbolometer sensors. To achieve low cost in a large dense array through batch fabrication.

APPROACH

Use a high thermal responsivity bolometric material (vanadium oxide) in composite air bridges to achieve a low Noise-Equivalent Power (NEP) bolometer array. The goal is to reach the phonon exchange minimum noise level for such devices. Design an array of efficient antennas for coupling to the bridges. They must have acceptance solid angles of 1 steradian or less in order to match an $f/1$ optical system, and load impedances to match the composite bridges. The overall focal plane array structure must be compatible with high yield batch processing.

WORK COMPLETED

A Low Noise-Equivalent Power (NEP) Microbolometer Air Bridge was Designed and Tested. This was a simple arched air bridge with vanadium oxide on the top, supported by silicon nitride. Figure 1 is a drawing showing the bridge, substrate and electrical ball bond contacts to pads at each end of the bridge, connected to the vanadium oxide. The vanadium oxide is in red (top) and the silicon nitride in blue (bottom).

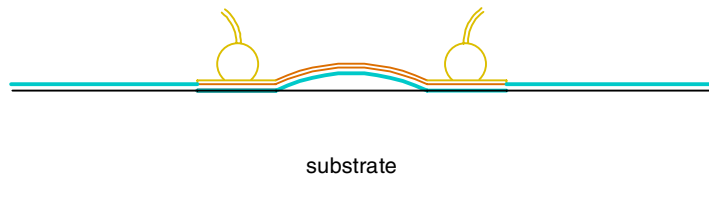


Figure 1. Drawing of Microbolometer Air Bridge.

The bridge is 50 microns long at its base and is 3 microns wide. The total thickness of the bridge is less than 1 micron. Putting the bridge in a bias circuit, and using a chopped laser excitation at various frequencies, the vanadium oxide response could be monitored. By this means, the response time of the bridge was measured. By calibrating the laser, the signal to noise level was measured. Specific measurements of spectral noise were made in connection with the electrical contacts between vanadium oxide and nichrome.

The Design of a Composite Bridge has been Completed. The bridge contains vanadium oxide as the bolometer, nichrome as the bolometer contacts, titanium as the antenna load, and silicon nitride as both support and insulator. All photolithographic masks associated with its fabrication, and materials for the rest of the sensor structure have been ordered and received. Work is in progress in preparing the first array of composite bolometer/bridges.

A Planar Antenna Design has been Completed. Figure 2 shows the directivity pattern for the antenna. There are actually two orthogonal cut planes shown, but they are so similar that they lay on top of each other in the figure. The main lobe pattern is therefore cylindrically symmetric. The base element is a bow tie configuration. The design was accomplished through the use of a 3D finite element RF mesh simulator. The 3D design model incorporates all the physical elements and their materials. The version shown has a peak directivity of 25, a beam acceptance solid angle of 0.5 steradians and a radiation efficiency of 93%.

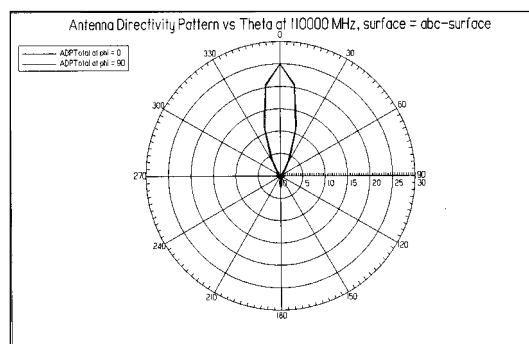


Figure 2. Antenna Directivity Pattern.

The Total Sensor Structure, with Vacuum Chuck, has been Designed. This includes the bolometer bridges, the antennas and the support structure. The specific fabrication steps are either worked out or being developed.

RESULTS

Thermal Response and Noise-Equivalent Power – Experimental Results. The bridge of Figure 1 was placed in a vacuum chamber and the peak-to-peak response was plotted versus chopping frequency. The results are shown in Figure 3.

The figure shows the data points and an analytical curve with parameters adjusted to fit the data. The calculated thermal response time was 220 microseconds, and the experimental value was 175 microseconds. This means that the thermal conductance to ground was 20% higher than anticipated (1.25×10^{-6} watts/K as opposed to 1×10^{-6} watts/K).

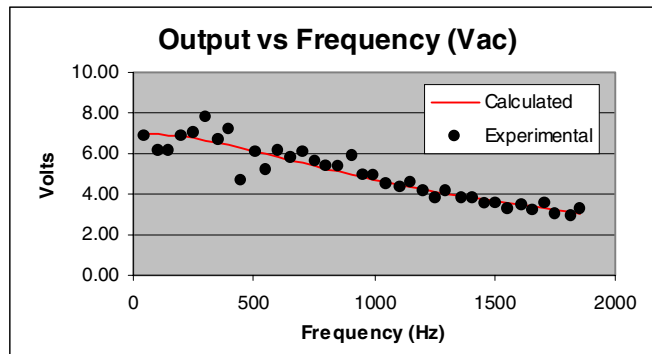


Figure 3. Peak-to-Peak Voltage Versus Chopping Frequency.

By calibrating the laser input, noise equivalent power could be determined. The results are shown in Figure 4. The chopping frequency was 209 Hz.

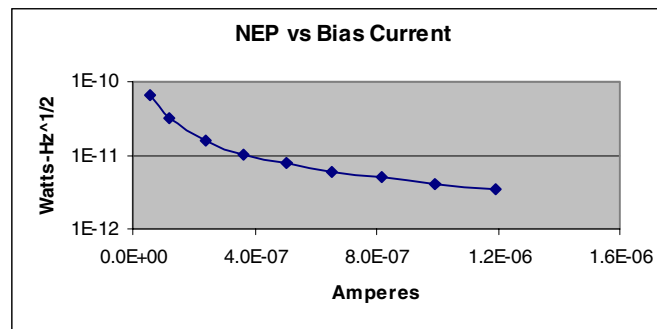


Figure 4. Noise Equivalent Power.

Note that it falls to about 3×10^{-12} Watts-Hz^{1/2} as the current exceeds 1 Microampere. This is close to the basic phonon exchange level, which is around 2×10^{-12} Watts-Hz^{1/2} for this case.

1/f Noise Measurements. Figure 5 is a noise plot of one of several samples tested.

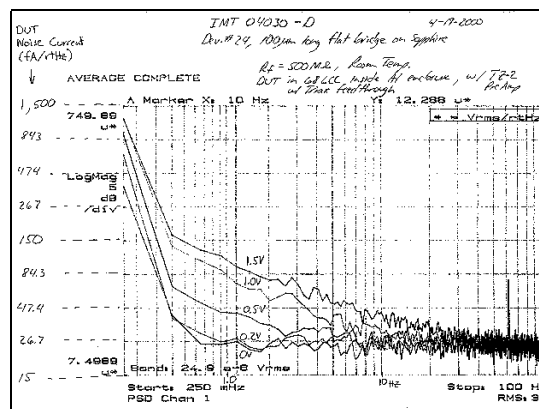


Figure 5. 1/f Noise Measurement.

This particular sample was a 50-micron flat bridge (not arched) with nichrome leads on a sapphire substrate. The $1/f$ “knee” frequency varied from less than 1 to 10 Hz as a function of bias. Translation of these results to the final sensor design leads to an anticipated knee frequency close to 1 Hz. This implies that the imager using these bolometers will not require a chopper.

Prototype Linear Array Layout. Figure 6 shows a top view of the basic platform on which the first prototype sensor array will be made.

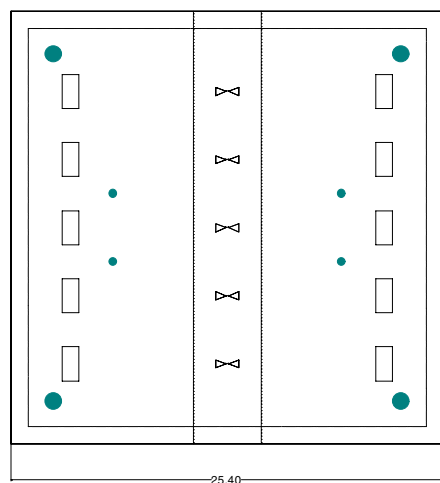


Figure 6. Top view of Basic Platform Layout.

It is a composite wafer slightly more than a millimeter thick. It contains five PMMW sensors in a vertical linear array down the middle. These can be identified in the figure from the bow tie antennas shown between the vertical dashed lines. The antennas are actually at the bottom face of the wafer and are shown through in this top view. The thermal bridges (with bolometers) are on the top face, but are too small to be shown at this scale. Figure 7 shows the mask layout of a bridge/bolometer structure.

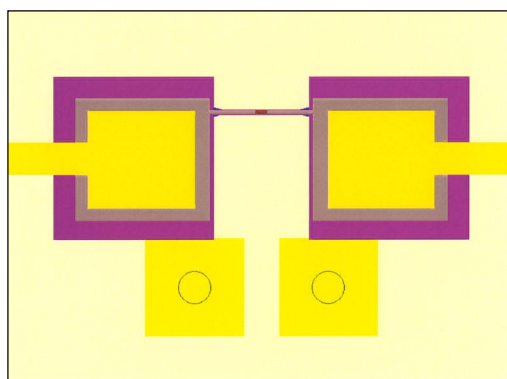


Figure 7. Mask Layout of Bridge/Bolometer Structure.

The bridge is the thin horizontal span in the top middle part of the figure. It is 75 microns long and 3 microns wide. The rest of the bridge layout is made up of electrical contact pads leading to bias and signal circuitry and the antenna arms. A single antenna pattern is shown in Figure 8. It is a detailed drawing of those shown in Figure 6. The holes near the center are for RF antenna leads.

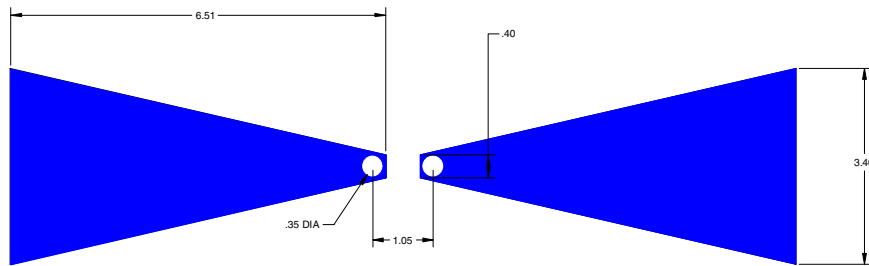


Figure 8. Single Antenna Pattern.

Summary. Preliminary measurements and experiments have been completed, leading up to the design and fabrication of an array of full composite bridge/bolometers. The fabrication of these is underway, and testing will immediately follow. Processing of a complete antenna-coupled microbolometer sensor array is scheduled for completion in the fourth quarter of CY 2000. Both laboratory testing and field imagery will be performed.

IMPACT/APPLICATIONS

Success in this program should lead to the first truly affordable passive millimeter wave imager with useful performance. Instead of fabricating single sensors and assembling them in an array, a whole focal plane array can be batch processed at once, along with its matching read out integrated circuit. This allows the affordable fabrication of large, dense staring arrays for the millimeter wave regime. The cost can be pennies per pixel, which is a factor of between one thousand and ten thousand less than the best projections for competing sensor technologies. This is anticipated to extend both military and commercial applications.

TRANSITIONS

Technology developed in this program has transitioned into an SBIR program sponsored by USSOCOM; contract USZA22-00-C-0005. The new contract is aimed at creating a modular focal plane comprised of individual 2D tiles. Each tile is a sub-array of sensors with its own matching readout integrated circuit. Special signal processing software will be developed to enhance the performance of the array. This SBIR is for special warfare airborne applications.

RELATED PROJECTS

IMT has recently completed its role in a program managed by Lockheed Martin Missiles and Fire Control – Orlando. The design is a dual mode (IR and PMMW) imaging system whose development is sponsored by the Justice Department through contract F30602-95-C-0272. This system uses TRF sensors (low noise W-band amplifiers followed by video detectors) with a variable speed scanning system. The application is for concealed weapons detection.

PATENTS

Patents on the bridge and antenna design are being applied for.